

Specification

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Title of the Invention

A powertrain for Hybrid Electric Vehicles

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Background of the Invention

This invention relates to a powertrain for hybrid electric vehicles that carry two drive sources, an internal combustion engine and electric motor on board.

The hybrid electric vehicle is propelled by one or both of the internal combustion engine and the electric motor, running according to driving conditions so as to reduce the air pollution resulting from the internal combustion engine and improve the fuel economy.

Such a type of the hybrid vehicle is shown in "Automotive Engineering/July 1997" (page 56-58). This powertrain includes an internal combustion engine, an electric motor, an electric generator, a battery and a power-split device.

20 The power-split device consists of one planetary gear set: it has a sun gear, a ring gear (an internal teethed gear), a planetary carrier. The ring gear is coaxial with the sun gear and the planetary carrier. The planetary carrier supports rotatably pinions meshing with both of the sun gear and the ring gear.

25 The sun gear is connected to the generator, the ring gear to

the motor, and the planetary carrier to the engine.

Its operations are as follows:

Startup, low-speed and low-speed deceleration operation:

5 The battery supplies the electric motor with electricity to propel the vehicle. The engine is stopped by fuel cut-off because its load is low in this operation.

Normal operation: The power-split device divides engine's output, one part driving the vehicle and the other 10 driving the generator to supply its electric output to the motor. The motor adds its output to the propulsion of the vehicle in addition to the power of the engine.

Full-throttle operation: The engine's full power is provided to the vehicle's wheels. In addition, the motor, 15 supplied with electricity from the battery, drives wheels to augment the drive power.

The above type of the prior powertrain, however, has following drawbacks:

20 In the normal operation, its maximum torque is not so large to drive medium- and heavy-duty vehicles such as commercial cars, buses or trucks. Besides its fuel efficiency is low.

The reason is as follows: As one part of engine's output is divided by the power-split device to drive the generator for 25 supplying its electric output to the motor in the normal operation,

the total efficiency includes a mechanical transmitting efficiency of the power-split device, an electricity-generating efficiency of the generator, an electricity-transmitting efficiency between the generator and the motor and a driving efficiency of the motor. This effects fuel consumption worse than vehicles with only a mechanical transmission.

Besides the power-split device has no ability to increase the engine's torque enough for driving medium- and heavy-duty vehicles.

#### Summary of the Invention

It is an object of the invention to provide a powertrain for hybrid electric vehicles that can obtain a large torque enough for driving medium- and heavy-duty vehicles such as trucks and commercial vehicles.

It is another object of the invention to provide a powertrain for hybrid electric vehicles that can reduce fuel consumption.

It is still another object of the invention to provide a powertrain for hybrid electric vehicles with a compact powertrain.

For the above purposes, in accordance with the present invention, there is provided a powertrain for hybrid electric vehicles comprising an internal combustion engine, an input shaft

connected to the engine, an output shaft, a plural sets of planetary gear sets between the input shaft and the output shaft, a first electric motor/generator and a second electric motor/generator.

5                   The planetary gear sets include a first planetary gear set and a second planetary gear set. The first planetary gear set has a first rotatable member, and the second planetary gear set has a second rotatable member. The first rotatable member establishes a reduced speed ratio when it is braked, and the  
10                  second rotatable member establishes an overdrive speed ratio when it is braked. The first electric motor/generator is connectable with the first rotatable member. The second electric motor/generator is connectable selectively with the second rotatable member or with the output shaft.

15                  Preferably, the plural sets of planetary gear sets may be comprised of two sets, the first planetary gear set and the second planetary gear set. The second planetary gear set has a driving member connectable with the second rotatable member via an idle gear.

20                  Preferably, the driving member may be connected with a shaft of a power take-off device.

                     Preferably, the plural sets of planetary gear sets may be composed of three sets, the first planetary gear set, the second planetary gear set, and a third planetary gear set. The  
25                  third planetary gear set has a third rotatable member to establish

a medium speed ratio when it is braked. And the first electric motor/generator is connectable selectively with the third rotatable member or with the second rotatable member.

Preferably, the one of the planetary gear sets may be 5 positioned to a first shaft, and the other to a second shaft parallel to the first shaft.

#### Description of the Accompanying Drawings

10 FIG.1 shows a powertrain for hybrid electric vehicles according to the first embodiment of the present invention.

FIG.2 shows a powertrain for hybrid electric vehicles according to the second embodiment of the invention.

15 FIG.3 shows a powertrain for hybrid electric vehicles according to the third embodiment of the invention.

FIG.4 shows a powertrain for hybrid electric vehicles according to the forth embodiment of the invention.

#### Description of the Embodiments

20 A powertrain for hybrid electric vehicles embodying the invention will be described hereafter by referring to the accompanying drawings.

FIG.1 shows a powertrain for hybrid electric vehicles 25 according to the first embodiment of the invention.

The powertrain for the hybrid vehicles carries an internal combustion engine 10 (such as a gasoline engine or a diesel engine), a first electric motor/generator 46, a second electric motor/generator 54, a battery (not shown), and two sets 5 of single-pinion type planetary gear sets (a first planetary gear set 20 and a second planetary gear set 30).

The both of the motors/generators 58, 59 can be shifted selectively to function as a motor that drives wheels or an electric generator that converts mechanical energy from the 10 engine 10 into electric energy for the motors and/or the battery when driven in a reverse rotation-direction.

The first planetary gear set 20 consists of three rotatable members: a first sun gear 22, a first ring gear (a first internal teethed gear) 24 coaxial with the first sun gear 22, and a first carrier 26 coaxial with the first sun gear 22. 15 The first carrier 26 supports rotatably first pinions 28 to mesh with both of the first sun gear 22 and the first ring gear 24. The first sun gear 22 comprises a first rotatable member that establishes a low-speed ratio when it is braked.

20 The second planetary gear set 30 also consists of three rotatable members: a second sun gear 32, a second ring gear (a second internal teethed gear) 34 coaxial with the second sun gear 32, and a second carrier 36 coaxial with the second sun gear 32. The second carrier 36 supports rotatably second pinions 38 to mesh with both of the second sun gear 32 and the second 25

ring gear 34.

The second sun gear 32 comprises a second rotatable member that establishes a high-speed ratio by a mechanical drive when it is braked.

5 The second ring gear 34 comprises a driving member, and the second pinion an idle gear.

An input shaft 12, united with a crankshaft of the engine 10, is connected to the second carrier 36 and a first drive gear 40a. The drive gear 40a meshes with a first driven gear 40b supported rotatably on a first shaft 16 parallel to the input 10 shaft 12 and an output shaft 14.

The first shaft 16 also supports rotatably a reverse gear 56 and is united with a fifth drive gear 58a. The drive gear 58a meshes with a fifth driven gear 58b united to an input shaft 60 of a power take-off device, such as a compressor of 15 air-conditioner, an oil pump of a power-steering device, an accessory, and the like. The reverse gear 56 and the first driven gear 40b are respectively positioned at each side of a first shifting mechanism 42, such as a dog clutch.

20 The first shifting mechanism 42 has a first sleeve 42a, a clutch gear 42b united with the first driven gear 40b and a clutch gear 42c united with the reverse gear 56. The sleeve 42a can be moved along with the first shaft 16 to mesh with one of 25 the clutch gears 42b, 42c or not to mesh with either of them (neutral position).

The first shaft 16 is also united with the first ring gear 24. The sun gear 22 is united with an output shaft 46a of the first motor/generator 46, and the first carrier 26 to a second drive gear 44a meshing with a second driven gear 44b. The second gear 44b is united to the output shaft 14.

On the other hand, the reverse gear 56 meshes with a third gear 48b supported rotatably on a second shaft 18. (The reverse gear 56 and the third gear 48b are drawn apart each other in Fig.1 for convenience.) The shaft 18, parallel to the input shaft 12 and the first shaft 16, supports rotatably a second drive gear 44c and a fourth driven gear 52a at each end of it. The drive gear 44c and the driven gear 52a are respectively positioned at each side of a second shifting mechanism 50 such as a dog clutch.

The second shifting mechanism 50 has a second sleeve 50a, a clutch gear 50b united with the third gear 48b and a clutch gear 50c united with the second gear 44c. The sleeve 50a can be moved along with the second shaft 18 to mesh with one of the clutch gears 50b, 50c or not to mesh with either of them (neutral position).

The second drive gear 44c meshes with the second driven gear 44b connected to the output shaft 14.

The forth driven gear 52a meshes with a fourth driven gear 52b united to an output shaft 54a of the second electric motor/generator 54.

The output shaft 14 is connected with a final drive (not shown) equipped with a differential gear device (not shown).

Supplying electricity to the motor/generator 46, 54 and operating the engine 10 and the motor/generator 46, 54 are controlled by a controller (not shown).

*f* The operations of the above powertrain are as follows.

First drive operation:

"A first drive operation" is defined as a drive mode that only the second motor/generator 54 drives the output shaft 10 to propel the vehicle.

On a departure and following acceleration, the first sleeve 42a is positioned at neutral position, while the second sleeve 50a meshes with the clutch gear 50c, thereby connecting the second gear 44c with the second shaft 18.

The battery supplies its electricity to the second motor/generator 54, but not to the first motor/generator 46. And fuel is cut to keep stopping the engine 10 because an engine's efficiency at partial load is low. Therefore only the second motor/generator 54 propels the vehicle via the fourth gears 52b, 52a, the second shaft 18, the second shifting mechanism 50, the second gears 44c, 44b, and the output shaft 14, which reduces fuel consumption.

In this operation, the fourth gears 52a, 52b increases the output torque of the second motor/generator 54 according

to their reduced speed ratio, and then the second gears 44b, 44c further increase the multiplied torque from the gears 52a, 52b according to their reduced speed ratio to output a large torque.

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Second drive operation:

"A second drive operation" is defined as the drive mode that the second motor/generator 54 drives the output shaft 14 with the first motor/generator 10 driven to generate via the first planetary gear set 20.

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(Starting the engine)

At need to generate by the first motor/generator 46 or to obtain a larger torque, the engine 10 is started as follows according to driving conditions:

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While parking or running at low-speed by drive of the second motor/generator 54, the battery supplies its electricity to the first motor/generator 46 through the first planetary gear set 20, the first shifting mechanism 42, and the first gears 20 40a, 40b, thereby driving the engine 10 to start.

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On the other hand, while running at high-speed by drive of the second motor/generator 54, the second motor/generator 54 drives the first motor/generator 46 to generate, thereby causing the engine 10 to start. This comes from the following 25 reason: when a torque from the second motor/generator 54 applies

the first motor/generator 46 in a reverse rotation-direction to generate, it causes reaction to rotate the first ring gear 24. The gear 24 drives the engine 10 to start in a forward rotation-direction via the first shifting mechanism 42, and the 5 first gears 40a, 40b. In both case, to start the engine 10, it is provided with fuel and ignition.

(Propelling the vehicle in the second drive operation)

In this operation, the vehicle is propelled as follows:

10 The engine 10 drives the output shaft 14 mechanically via the second planetary gear set 30, and also the first motor/generator 46 to generate. This generated electric power is transmitted to the second motor/generator 54 to drive the output shaft 14 with or without electric drive power from the 15 battery. Therefore the second motor/generator 54 is supplied to propel the vehicle in the second drive operation with electricity from the battery and the first motor/generator 46 driven by the engine 10, or from only the latter. In this operation, 20 one part of the generated electric power may be transmitted to the battery.

Third drive operation:

"A third drive operation" is defined as the drive mode that the vehicle is propelled mechanically at a constant reduced 25 speed ratio obtained by braking the first sun gear (the first

rotatable member) 22.

In the second drive operation, the rotation-speed ratio (the rotation-speed of the input shaft 12 divided by that of the output shaft 14), equal to the reciprocal number of the gear ratio, is determined according to a torque from the engine 10, a load applied on the output shaft 14, and the amount of electricity transmitting between the second motor/generator 54 and the battery. The electric power generated by the first motor/generator 46 also changes according to them.

When the torque of the engine 10 and the load on the output shaft 14 are large, the rotation-speed of the input shaft 10 is very faster than that of the output shaft 14 at the beginning. As the vehicle's speed increases gradually, the load on the output shaft 14 becomes small. The rotation-speed of the output shaft 14 changes continuously to rise under a constant speed of the input shaft 12, and the speed of the first motor/generator 46 drops.

Increasing the vehicle's speed or decreasing the engine's speed causes the first sun gear 22 and the first motor/generator 46 to reduce their speeds and stop finally. To keep them braked, it is necessary for the battery to supply its electricity to the first motor/generator 46 to output torque in a forward rotation-direction. Its electricity's amount is small because a motor outputs the largest torque when motor's speed is zero.

So this brings the third drive operation that the engine's power is transmitted mechanically at a constant reduced speed ratio of  $i_4 \times (1 + \alpha_1) \times i_2$  by braking the first sun gear (the first rotatable member) 22 where a teeth-number ratio of 5 the first sun gear 22 to the first internal teathed gear 24 is  $\alpha_1$ , a teeth-number ratio of the first gears 40a, 40b is  $i_4$ , and the teeth-number ratio of the second gear 44a, 44b is  $i_2$ .

As the first motor/generator 46 does not generate in this operation, the engine 10 is able to drive the vehicle 10 mechanically without the drive of the second motor/generator 54, which is idling, or to drive it with the drive of the drive 15 of the second motor/generator 54 supplied from the battery with its electricity. Also the engine 10 can drive the second motor/generator 68 mechanically at the reduced ratio to generate electricity to charge the battery.

#### Fourth drive operation:

"A fourth drive operation" is defined as the drive mode that the first motor/ generator 46 drives the first sun 20 gear 22 with the second motor/generator 54 driven by the second sun gear 32 to generate.

In the third drive operation, the second planetary gear set 30 is kept a neutral state, which does not transmit power, when the battery does not supply its electricity to the 25 second motor/generator 54.

The third gear 48b rotates at almost the same speed as the second shaft 18 during the third drive operation when the gear ratios of the second gears 44b, 44c and the third gears 48a, 48b are set to adjust properly to the gear ratio  $\alpha_2$  (the 5 teeth-number ratio of the second sun gear 32 to the second ring gear 34).

To shift from the third drive operation to the fourth one, the battery stops its electric supply to the second motor/generator 54, and the first sleeve 59a of the first shifting mechanism 50 is moved to engage with the clutch gear 50b to connect the second shaft 18 with the third gear 48b. This shift is achieved smoothly, for the rotation speed of the second shaft 18 is almost the same as the third gear 48b. This causes the second motor/generator 54, connected with the second sun gear 32, to 10 rotate. Then second motor/generator 54 supplies its electricity to the first motor/generator 46, which causes the first motor/generator 46 to start to rotate in the forward direction. 15 Its output torque drives the output shaft 14 via the first planetary gear set 20 and the second gears 44a, 44b.

20 In detail, the first sun gear 22, driven by the first motor/generator 46, drives the second carrier 36 at the reduced gear ratio, and its reaction torque applies to the input shaft 12 through the first ring gear 24, the first shifting mechanism 42 and the first gears 40a, 40b. This torque to the 25 second carrier 36 united with the input shaft 12 is smaller than

the output torque of the engine 10.

As seen above, the most part of the output from the engine 10 drives mechanically the output shaft 14 via the both planetary gear sets 20, 30, and the rest drives the second 5 motor/generator 54 to generate electricity for supplying to the first motor/generator 46 to drive the output shaft 14.

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Fifth drive operation:

"A fifth drive operation" is defined as a drive mode 10 that the vehicle is propelled mechanically at a constant overdrive speed ratio obtained by braking the sun gear (the second rotatable member) 32.

The rotation-speed ratio in the fourth drive operation depends on the torque from the engine 10, the load 15 applied on the output shaft 14, and the amount of electricity transmitting between the second motor/generator 54 and the battery. The electric power generated by the second motor/generator 54 also changes according to them.

When the torque of the engine 10 and the load on the 20 output shaft 14 are large, the rotation-speed of the input shaft 10 is very faster than that of the output shaft 14 at the beginning. As the vehicle's speed increases gradually, the load on the output shaft 14 becomes small. The rotation-speed of the output shaft 14 changes continuously to rise under a constant speed of the 25 input shaft 12, and the speed of the second motor/generator 54

drops.

Increasing the vehicle's speed or decreasing the engine's speed causes the second sun gear 32 and the second motor/generator 54 to reduce their speeds and stop finally. To 5 keep them braked, it is necessary for the battery to supply its electricity to the second motor/generator 54 to output torque in a forward rotation-direction.

So this brings the fifth drive operation that the engine's power is transmitted mechanically at a constant 10 overdrive speed ratio of  $1/(1+\alpha_2)$ .

In the fifth drive operation, the engine 10 drives the output shaft 14 mechanically at the overdrive ratio with the drive of the first motor/generator 46, supplied electricity from the battery, or drives the shaft 14 and the first motor/generator 15 to generate for charging the battery.

Therefore the powertrain is able to sift continuously from the first drive operation to the fifth drive operation including the reduced gear ratio and the overdrive one, thereby starts the vehicle and run at high speed.

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(Slow down the vehicle and Braking)

To reduce the vehicle speed slowly or to apply brake at a high-speed in the third drive operation ~ the fifth drive operation: the engine's fuel is cut, and the battery is charged 25 by the first motor/generator 46 or the second motor/generator

54 in the reverse of function between a motor and a generator in the forward drive so as to obtain charge as much as can. This causes the vehicle's speed to drop.

At a low-speed, engaging the first sleeve 42a with 5 the clutch gear 42b, and the second sleeve 50a with the clutch gear 50c shown in Fig.1, the engine 10 is stopped and the second motor/generator is driven to generate, which reduces the vehicle's speed.

Controlling both motor/generator 46, 54 and 10 charging braking energies to the battery (regeneration) causes the vehicle to drop its speed at the desirable deceleration rate, which brings fuel economy to improve.

#### Reverse drive operation:

"A reverse drive operation" is defined as a drive mode that the second motor/generator 54 drives the output shaft 14 to propel the vehicle backward.

In order to drive backward, the first shifting mechanism 42 and the second shifting mechanism 50 are shifted 20 as follows: the sleeve 42a is moved to mesh with the clutch the gear 44c, which brings the first ring gear 40b to be disengaged from the first gear 40b. The sleeve 50a is moved to mesh the clutch gear 50c, which brings the first ring gear 24 to be connected to the reverse gear 56.

25 When the engine 10 is stopped, the battery supplies

its electricity to the second motor/generator 54 to output a torque in a reverse rotation-direction, thereby starting and accelerating the vehicle backward.

When the engine 10 runs to drive the first motor/generator 46 to generate, the second sun gear 32 and the first ring gear 24 are connected through the third gears 48a, 48b, and reverse gear 56, which brings the first ring gear 24 to be rotated in the opposite rotation-direction to the rotation-direction under the second drive operation.

Specifically, the torque from the engine 10 is transmitted to the second planetary gear set 30 through the input shaft 12 to the second carrier 36, and then divided here: one part of the torque drives the output shaft 14 via the ring gear 34, and the rest drives the second sun gear 32 in the forward rotation-direction. This gear 32 rotates the first ring gear 24 in the reverse rotation-direction. In this case, the third gear 48b works as an idle gear, thereby the first ring gear 24 drives the first carrier 26 at a reduced gear ratio in the reverse rotation-direction, and its reaction drives the first sun gear 22 to rotate in the forward direction. The first sun gear 22 supplies its generated electric power to the second motor/generator 54 via the controller. Although, in the backward drive, the torque from the second ring gear 34 drives the output shaft 14 in the forward-direction, the larger torque from the first carrier 26 and the second motor/generator 54 drives it

in the reverse-direction, which causes a reverse-direction torque as large as the second drive operation.

Power take-off operation:

5 "A power take-off operation" is defined as a drive mode that take-off devices, such as oil pumps of power steering device and compressors of air conditioners, is driven the engine 10 or the first motor/generator 46.

10 When the engine 10 runs, the sleeve 42a of the first shifting mechanism 42 is moved to engage with the clutch gear 42b. So the engine 10 drives the shaft 60 of the power take-off device via the first gears 40a, 40b, the first shifting mechanism 42 and the fifth gears 58a, 58b.

15 When the engine 10 is stopped for parking and the like, the first shifting mechanism 42 is kept at neutral, and the battery supplies electricity to the first motor/generator 46 to drive in the reverse direction. This causes the first ring gear 24 to rotate in the forward direction and drive the shaft 60. As the backward-direction torque applies to the first carrier 20 26 in this case, it is necessary for a parking brake device to brake the wheels, or for the second motor/generator 54 to apply the forward torque to the wheel to cancel the backward-direction torque. Therefore the powertrain can drive the power take-off device for cars, dump trucks, fire engines, dustcarts, and so 25 on both at parking and at vehicle running.

As has been noted above, the powertrain of the first embodiment can drive in the 5 forward drive operations including the reduced gear ratio and the overdrive gear ratio, the backward drive operation, and the power take-off drive operation. These 5 forward drive operations are shifted continuously from one to another, and enable to obtain large torque sufficient for hill-climbing or rapid acceleration and also to improve fuel economy at low or medium speed. Besides the second motor/generator 54 may be a small one, for its output is multiplied by the gear ratios of the fourth gears 52a, 52b and the second gears 44b, 44c.

FIG.2 shows a powertrain for hybrid vehicles according to the second embodiment of the invention, whose parts of similar to the embodiment of Fig.1 are denoted by the same reference numerals, and their explanation are abbreviated here.

This powertrain has, as the same as that of Fig.1, the engine 10, the input shaft 12, the output shaft 14, the first electric motor/generator 46, the second electric motor/generator 54, the battery (not shown), and two sets of single-pinion typed planetary gear sets (the first planetary gear set 20 and the second planetary gear set 30).

The first sun gear 22 of the first planetary gear set 20 comprises a first rotatable member that establishes a low

speed ratio when it is braked.

The second sun gear 32 comprises a second rotatable member that establishes an overdrive speed ratio by a mechanical drive when it is braked.

5 The first shaft 16 supports a reverse gear 75b to mesh with a reverse gear 75a rotatable on the second shaft 18. (The reverse gears 75a, 75b are drawn apart each other in Fig.2 for convenience.) The first shaft 16 also supports rotatably the reverse gear 75b, the clutch gears 42b, 42c, and a first driven gear 19b. The clutch gear 42b is united with the reverse gear 75b, and the clutch gear 42c with the first driven gear 19b. The first shaft 186 is selectively joined to one of the clutch gear 42b, 42c by the movable sleeve 42a, or not to either. The sleeve 42a and the clutch gear 42b, 42c comprise the first shifting means 42.

10 The second shaft 18, also as an output shaft of the second motor/generator 54, supports rotatably the reverse gear 75a, a first driven gear 19c, and a clutch gear 50b. The reverse gear 75a, the clutch gear 50b, and the first driven gear 19c are united all together. The first driven gear 19c meshes a first drive gear 19a connected to the second sun gear 32. The second shaft 18 also supports rotatably a clutch gear 50c and a second drive gear 44c united with the gear 50c. The second shaft 18 is selectively joined to one of the clutch gear 50b, 50c by the 15 movable sleeve 50a, or not to either. The sleeve 50a and the 20

clutch gear 50b, 50c comprise the second shifting means 50.

This powertrain of the second embodiment drives in the 5 forward drive operations and the backward operation as the same as that of the first embodiment.

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FIG. 3 shows a powertrain for hybrid vehicles according to the third embodiment of the invention, whose parts of similar to the embodiment of Fig. 1 are denoted by the same reference numerals.

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In this embodiment, the planetary gear sets are comprised of three sets.

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The powertrain carries the internal combustion engine 10, the first electric motor/generator 46, the second electric motor/generator 54, the battery (not shown), and three sets of single-pinion type planetary gear sets (the first planetary gear set 20, the second planetary gear set 30, and a third planetary gear set 72).

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The both of the motors/generator 68, 71 can be shifted selectively to function as a motor that drives wheels (not shown) or an electric generator that converts mechanical energy from the engine 10 into electric energy for the motors and/or the battery when driven in a reverse rotation-direction.

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The first and the second planetary gear sets 20, 30 are supported on an input shaft 12 coaxial with the output shaft 14. The third planetary gear set 72 is supported on the first

shaft 16 parallel to the input shaft 12 and the output shaft 14.

The first planetary gear set 20 consists of three rotatable members: the first sun gear 22, the first ring gear (the first internal toothed gear) 24 coaxial with the first sun gear 22, and the first carrier 26 coaxial with the first sun gear 22. The sun gear 22 is united with the input shaft 12 connected to the crankshaft of the engine 10. The first carrier 26 supports rotatably first pinions 28 to mesh with both of the sun gear 22 and the ring gear 24, and is connected to the output shaft 14. The ring gear 24 is united with the first driven gear 40a to engage with the first drive gear 540b. The first sun gear 22 comprises a first rotatable member that establishes a low-speed ratio when it is braked.

The second planetary gear set 30 also consists of three rotatable members: the second sun gear 32, the second ring gear (the second internal toothed gear) 34 coaxial with the second sun gear 32, and the second carrier 36 coaxial with the second sun gear 32. The second carrier 36 supports rotatably second pinions 38 to mesh with both of the second sun gear 32 and the second ring gear 34. The sun gear 32 is united with a third drive gear 73a, the carrier with the input shaft 12, and the ring gear 34 with the first carrier 26. The second sun gear 32 comprises a second rotatable member that establishes a high-speed ratio by a mechanical drive when it is braked.

The third planetary gear set 72 also consists of three rotatable members: a third sun gear 76, a third ring gear (a second internal toothed gear) 78 coaxial with the second sun gear 76, and a third carrier 77 coaxial with the second sun gear 76. The sun gear 76 is united with a fourth idle gear 60a to mesh with a forth driven gear 60b. The fourth driven gear 60b, connected to the output shaft 14, meshes with a fourth drive gear 60c. The third carrier 77 supports rotatably third pinions 79 to mesh with both of the sun gear 76 and the ring gear 78, and is united with the first shaft 16. The ring gear 78 is united with a sixth driven gear 70a to mesh with a sixth drive gear 70b. The first shaft 16 is connected to a third driven gear 73c to mesh with the fourth drive gear 73a.

The fourth drive gear 73a meshes with a driven gear 73c united with a clutch gear 80b. The clutch gear 80b is supported rotatably on a second shaft 18 to support a clutch gear 80c united with a second driven gear 74a. The second driven gear 74a, connected to the second shaft 18, meshes with a second drive gear 74b united with an output shaft 46a of the first motor/generator 46. The second shaft 18 is selectively joined to one of the clutch gear 80b, 80c by a movable sleeve 80a, or not to either. The sleeve 80a and the clutch gear 80b, 80c comprise a first shifting means 80.

The sixth driven gear 70a meshes with a sixth drive gear 70b, united with a clutch gear 62b, on a third shaft 64.

The third shaft 64 also supports rotatably a clutch gear 62c and the fourth drive gear 60c united each other. The third shaft 64 is selectively joined to one of the clutch gear 62b, 62c by a movable sleeve 62a, or not to either. The sleeve 62a and the 5 clutch gear 62b, 62c comprise a second shifting means 62.

The third shaft 64 is parallel to the input shaft 12, the output shaft 14, the first shaft 16 and the second shaft 18, and united with a fifth drive gear 66a to mesh a fifth driven gear 66b. The gear 66b is united with an output shaft 54a of 10 the second motor/generator 54.

Supplying electricity to the motor/generator 46, 54 and operating the engine 10 and the motor/generator 46, 54 are controlled by a controller (not shown)

15 The operations are as follows:

First drive operation:

"A first drive operation" is defined a drive mode that only the second motor/generator 54 drives the output shaft 14 to propel the vehicle.

20 On this departure and following acceleration, the first sleeve 80a is positioned at neutral position, while the second sleeve 62a meshes with the clutch gear 62c, thereby connecting the fourth gear 60c with the third shaft 64.

The battery supplies electricity to the second 25 motor/generator 54, but not to the first motor/generator 46.

And fuel is cut to keep stopping the engine 10. Therefore only the second motor/generator 54 drives the output shaft 14 to propel the vehicle through the fifth gears 66a, 66b, the third shaft 64, the second shifting mechanism 62, and the fourth gears 60a, 5 60b, 60c.

Second drive operation:

"A second drive operation" is defined as the drive mode that the second motor/generator 54 drives the output shaft 14 to propels the vehicle with the first motor/generator 46 driven to generate via the first planetary gear set 20.

(Starting the engine 10)

At need to generate by the first motor/generator 46 or to obtain a larger torque, the engine 10 is started as follows according to driving conditions:

While parking or running at a low speed by the drive of the second motor/generator 54, the battery supplies its electricity to the first motor/generator 46. It drives the engine 20 10 to start via the second gears 74a, 74b, the first shifting mechanism 80, the third gears 73a, 73c, the first planetary gear set 20 and the input shaft 12.

On the other hand, while running at high speed by the drive of the second motor/generator 54, the second 25 motor/generator 54 drives the first motor/generator 46 to

generate, thereby causing the engine 10 to start. . In both case, to start the engine 10, it is provided with fuel and ignition.

(Driving by the second motor/generator 54 with the engine 10  
5 running)

The engine 10 drives the first sun gear 22 to reduce a rotation-speed of the first carrier 26 and the output shaft 14 united therewith. The carrier 26 causes reaction to drive the first ring gear 24 in the reverse direction, which brings 10 the first motor/generator 46 to generate electricity. The electricity is provided to the second motor/generator 54 to drive through the controller.

In the second drive operation the vehicle is, therefore, propelled by a torque transmitted mechanically from 15 the engine 10 via the first planetary gear set 20, and a torque transmitted from the second motor/generator 54.

#### Third drive operation:

"A third drive operation" is defined as the drive mode 20 that the vehicle is propelled mechanically at a constant reduced speed ratio obtained by braking the first sun gear (the first rotatable member) 22.

The speed ratio in the second operation depends on the torque from the engine 10, the load on the output shaft 14, 25 and the electric power provided from the battery to the second

motor/generator 54. The electric power generated by the first motor/generator 56 also varies according to them.

Like the case of the first embodiment, when the torque of the engine 10 and the load on the output shaft 14 are large, 5 the rotation-speed of the input shaft 10 is very faster than that of the output shaft 14 at the beginning. So the vehicle's speed increases gradually, the load on the output shaft 14 becomes small. The rotation-speed of the output shaft 14 changes continuously to rise under a constant speed of the input shaft 10, and the speed of the first motor/generator 56 reduces.

Increasing the vehicle's speed or decreasing the engine's speed causes the first ring gear 24 and the first motor/generator 46 to reduce their speeds and stop finally. To 15 keep them braked, it is necessary for the battery to supply its electricity to the first motor/generator 46 to output torque in a forward rotation-direction.

Braking the first ring gear (the first member) 24 brings the third operation that the second motor/generator 54 drives at reduce speed ratio of  $(1 + \alpha_1) / \alpha_1$ . As the first motor/generator 46 does not generate in this operation, the 20 engine 10 is able to drive the vehicle mechanically without the drive of the second motor/generator 54, which is idling, or to drive it with the drive of the drive of the second motor/generator 54 supplied from the battery with its electricity. Also the second 25 motor/generator 68 can be driven to generate electricity to

charge the battery.

Fourth drive operation:

"A fourth drive operation" is defined as the drive mode  
5 that the first motor/generator 46 drives the output shaft 14  
via the planetary gear set 20 with the second motor/generator  
54 driven via the second planetary gear set 30 and the third  
planetary gear set 72.

When the second motor/generator 54 is idling, no torque  
10 applies the second shifting mechanism 62. So adjusting the gear  
ratios properly, the fifth gear 66a rotates at almost the same  
speed as the sixth gear 70b, which enables the second sleeve  
62a to engage with the clutch gear 62b smoothly. This causes  
the third ring gear 78 to connect with the second motor/generator  
15 54. It supplies its generated electricity to the first  
motor/generator 46 to drive, which causes the gear ratio to change  
smaller than that in the third drive operation.

In the fourth drive operation the first  
motor/generator 46 drives the output shaft 14 through the first  
20 planetary gear set 20, which causes reaction to the first sun  
gear 22 to rotate, thereby torque inputted to the second planetary  
gear set 30 from the engine 10 becomes small. This means that  
the engine 10 drives the first motor/generator 54 to generate  
via the second planetary gear set 30 and the third planetary  
25 gear set 72 but its generated amount becomes small. In the fourth

drive operation the engine 10 drives the output shaft 14 mechanically, which improves the fuel economy than in the second drive operation.

5                         Fifth drive operation:

"A fifth drive operation" is defined as the drive mode that the vehicle is propelled at a medium speed ratio obtained by stopping the third ring gear (the third rotatable member) 44.

10                         The speed ratio in the fourth drive operation depends on the torque of the engine 10, the load on the output shaft 14, and the electricity transmitting between the battery and the second motor/generator 46. The electricity generated by the second motor/generator 54 also depends on them.

15                         When the torque of the engine 10 and the load on the output shaft 14 are large, the rotation-speed of the input shaft 10 is very faster than that of the output shaft 14 at the beginning. As the vehicle's speed increases gradually, the load on the output shaft 14 becomes small. The rotation-speed of the output shaft 20 14 changes continuously to rise under a constant speed of the input shaft 12, and the speed of the second motor/generator 46 drops.

25                         Increasing the vehicle's speed or decreasing the engine's speed causes the third ring gear 78 and the second motor/generator 54 to reduce their speeds and stop finally. To

keep them braked, it is necessary for the battery to supply its electricity to the second motor/generator 54 to output torque in a forward rotation-direction.

Braking the third ring gear (the third member) 78 5 brings the fifth operation that the engine 10 drives at a medium speed ratio of  $\{(1+\alpha_3) + \alpha_2 \times \alpha_2 \times i_3 \times i_4\} / \{(1+\alpha_2) \times (1+\alpha_3)\}$ , where the teeth-number ratio of the third gears is  $i_3$ , and that of the fourth gears 60a, 60b is  $i_4$ .

As the second motor/generator 54 does not generate in 10 the fifth drive operation, the engine 10 is able to drive the vehicle mechanically without the drive of the first motor/generator 46, which is idling, or to drive it with the drive of the drive of the first motor/generator 46 supplied from the battery with its electricity. Also the first motor/generator 15 46 can be driven to generate electricity to charge the battery.

#### Sixth drive operation:

"A sixth drive operation" is defined as the drive mode that the second motor 54 drives the output shaft 14 via the third 20 planetary gear set 72 with the first motor/generator 46 driven via the second planetary gear set 30 to generate.

When the first motor/generator 46 is idling, no torque applies the first shifting mechanism 80. So adjusting the gear ratios properly, the first gear 40b rotates at almost the same 25 speed as the third gear 73c, which enables the first sleeve 80a

to engage with the clutch gear 80b smoothly. This causes the second sun gear 32 to connect with the first motor/generator 46. It supplies its generated electricity to the second motor/generator 54 to drive, which causes the reduced gear ratio 5 to change smaller than that in the fifth drive operation.

In the sixth drive operation the second motor/generator 54 drives the output shaft 14 via the third planetary gear set 72 with the first motor/generator 54 driven via the second planetary gear set 30 to generate. The most part of the engine's 10 output drives the output shaft 14 by a mechanical transmission, which brings to improve fuel economy better than the second drive operation.

#### Seventh drive operation:

"A seventh drive operation" is defined as the drive mode that the second planetary gear set 30 gives a mechanical overdrive gear ratio by stopping the second sun gear 32.

The speed ratio in the seventh drive operation depends on the torque of the engine 10, the load on the output shaft 20 14, and the electricity transmitting between the battery and the second motor/generator 46. The electricity generated by the first motor/generator 46 also depends on them.

When the torque of the engine 10 and the load on the output shaft 14 are large, the rotation-speed of the input shaft 25 10 is very faster than that of the output shaft 14 at the beginning.

As the vehicle's speed increases gradually, the load on the output shaft 14 becomes small. The rotation-speed of the output shaft 14 changes continuously to rise under a constant speed of the input shaft 12, and the speed of the first motor/generator 46 drops.

Increasing the vehicle's speed or decreasing the engine's speed causes the second sun gear 32 and the first motor/generator 46 to reduce their speeds and stop finally. To keep them braked, it is necessary for the battery to supply its electricity to the first motor/generator 46 to output torque in a reverse rotation-direction.

Braking the second sun gear 32 brings the seventh operation that the engine 10 drives at a overdrive speed ratio of  $1/(1+\alpha_2)$  mechanically via the second planetary gear set 30 by braking the second sun gear 32. In this operation, the engine 10 drives the output shaft 14 with the drive of the second motor/generator 54, supplied with electricity from the battery, or drives the shaft 14 and the second motor/generator 54 to generate electricity for charging the battery.

#### Reverse drive operation:

"A reverse drive operation" is defined as the drive mode that the second motor/generator 54 drives the output shaft 14 in the reverse rotation-direction to propel the vehicle backward.

In order to drive backward, the first shifting mechanism 80 and the second shifting mechanism 62 are shifted as follows: the first sleeve 80a is moved to mesh with the clutch the gear 480b, which brings the second sun gear 32 to connect 5 with the first motor/generator 46. The second sleeve 62a engages with the clutch gear 62c.

Reverse drive when the engine 10 is stopped: the battery supplies its electricity to the second motor/generator 54 to output a torque in a reverse rotation-direction, thereby 10 starting and accelerating the vehicle backward.

Reverse drive when the engine 10 runs to drive the input shaft 12, the torque inputted to the second carrier 36 via the input shaft 12 is divided by the second planetary gear set 30: one part of the torque drives the output shaft 14 via 15 the second ring gear 34 in the forward direction, and the rest drives the first motor/generator 46 to generate electricity. This generated electricity is supplied to the second motor/generator 54 to propel the output shaft 14 in the reverse direction. The torque of the output shaft 14 in this case is 20 smaller than the case of supplying electricity from the battery.

As has been noted above, the powertrain of the third embodiment can drive in the 7 forward drive operations including the reduced gear ratio, the medium gear ratio, the overdrive gear ratio, and the backward drive operation. These 7 forward 25 drive operations are shifted continuously from one to another,

and enable to obtain large torque sufficient for trucks and the like. And they also improve fuel economy at low or medium speed. Besides Regeneration by the both motor/generator 46, 54 during braking also improve fuel economy.

5

FIG. 4 shows a powertrain for hybrid vehicles according to the fourth embodiment of the invention, whose parts of similar to the embodiments of Fig.1, Fig.3 are denoted by the same reference numerals, and their explanation are abbreviated here.

10 The powertrain of this embodiment also has three planetary gear sets; the first planetary gear set 20 on the input shaft 12, the second planetary gear set 30 on first shaft 16a, 16b, the third planetary gear set 72 on the second shaft 18.

15 The first sun gear 22 is connected to the input shaft 12 and a first drive gear 82a. The first carrier 26 is united with a second drive gear 81a and the output shaft 14. The ring gear 24 is united with a third drive gear 83a, both of which are supported rotatably on the output shaft 14.

20 The second sun gear 32 is united with a fifth drive gear 66a to mesh with a fifth driven gear 66b. The second carrier 36 is connected to the first shaft 16a. The ring gear 34 is united with the second idle gear 81b, both of which are supported rotatably on the first shaft 16a parallel to the input shaft 12. The second idle gear 81b meshes with a second driven gear 25 81d.

The third sun gear 42 is united with a second driven gear 81c to mesh with a second drive gear 81a. The second drive gear 81a also meshes with the second idle gear 81b. The third carrier 45 is connected to the second shaft 18a parallel to the 5 input shaft 12 and the first shaft 16. The third ring gear 44 is united with the clutch gear 80b.

Coaxial with the second shaft 18a, a second shaft 18b is arranged to support rotatably the clutch gear 80c and a third driven gear 83b united with the gear 80c. The third driven gear 83b meshes with the third drive gear 83a. The second shaft 18b is selectively joined to one of the clutch gears 80b, 80c by the movable sleeve 80a, or not to either. The sleeve 80a and the clutch gears 80b, 80c comprise a first shifting means 80. The second shaft 18b is connected to a fourth driven gear 85a 15 to mesh a fourth drive gear 85b united with an output shaft 46a of the first motor/generator 46.

Parallel to the input shaft 12, the first shaft 16a and the second shafts 18a, 18b, a third shaft 64 is arranged to support rotatably clutch gears 62b, 62c, a second driven gear 20 81d and a fifth driven gear 66b. The third shaft 64 is selectively joined to one of the clutch gear 62b, 62c by the movable sleeve 62a, or not to either. The sleeve 62a and the clutch gear 62b, 62c comprise the second shifting means 62.

The fifth driven gear 66b meshes with a fifth drive 25 gear 66a connected to the first shaft 16b coaxial to the first

shaft 16a. The third shaft 64 is connected to a sixth drive gear 84a to mesh with a sixth driven gear 84b secured to an output shaft 54a of the second motor/generator 54.

The first drive gear 82a, connected to the input shaft 5 12, meshes with a first driven gear 82b connected to the first shaft 16a and with a first driven gear 82c connected to the second shaft 18a.

This powertrain of the fourth embodiment drives in the 10 7 forward drive operations and the backward operation as the same as that of the third embodiment.

The present disclosure relates to subject matters in Japanese Patent Applications No. Hei 11-175885 filed on May 19, 1999 (Publication No. 2000-326739 published on November 28, 15 2000) and No. Hei 11-220333 filed on June 29, 1999 (Publication No. 2001-010361 published on January 1, 2001), which is expressly incorporated herein by reference in its entirety.